STUDIES OF THE AURORAL SUBSTORM

III. Concept of the Magnetospheric Substorm and its Relation to Electron Precipitation and Micropulsations

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MAGNETOSPHERIC SUBSTORMS

ABSTRACT

The concept of the auroral substorm is reviewed in terms of recent satellite measurements of the magnetospheric effects of a substorm, and a more general and inclusive terminology, the *magnetospheric substorm,* is suggested. In support of this suggestion it is shown that the various forms of geomagnetic micropulsations and energetic electron precipitation which have been discussed in papers I and II occur at their respective local times during a substorm. Balloon x-ray and micropulsation data obtained by the Berkeley group as well as riometer absorption, earth currents and standard magnetograms from several auroral zone stations have been used.

INTRODUCTION

In papers I and II it was shown that the forms and temporal characteristics of energetic electron precipitation and micropulsation activity are determined by the local time of occurrence. The purpose of this paper is to present evidence that these various types of activity do not occur randomly, but occur primarily at times when an auroral substorm (Akasofu, 1964) is in progress. Balloon x-ray and micropulsation data obtained by the Berkeley group during parts of August, 1965 and September, 1966 will be used to show that whenever an electron precipitation and micropulsation event occurred, regardless of the local time of observation, an auroral substorm is in some phase of its development on the night side of the earth. Standard magnetograms from various auroral zone stations are used to ascertain the occurrence of an auroral substorm. No attempt will be made to relate a particular form of energetic electron precipitation and micropulsation to a specific phase of an auroral substorm, nor will the problem of possible systematic time delays between stations at different local times be discussed.

MAGNETOSPHERIC SUBSTORM

Before presenting the observational results, the question arises as to the appropriate terminology to describe the complicated physical processes occurring in the magnetosphere which produce an auroral substorm. The concept of the auroral substorm was introduced by Chapman and Akasofu (Akasofu, 1964) to describe the characteristic disturbed forms of the aurorae at different times and different longitudes after the breakup of the auroral arcs around local midnight. The term substorm indicates that these auroral disturbances are a fundamental part of the long-lived geomagnetic main phase storms. In view of recent satellite observations, Anderson (private communication) and Brice (private communication) have suggested that the concept of the auroral substorm be generalized to include all of the associated magnetospheric phenomena. In order to emphasize this point we will review some of the magnetospheric observations that relate to auroral substorms.

Several correlation studies between magnetospheric fields and particles measurements and auroral disturbances have appeared in the recent literature. Anderson (1965) observed that the 40 keV electron islands in the tail of the magnetosphere occurred more frequently during times of high A_p. Behannon and Ness (1966) found that the magnitude of the magnetic field in the tail of the magnetosphere generally increases during the main phase storm, and that it decreased during a substorm. Heppner, et al (1967) also found that the magnetic field in the region 10 to 16 R_e decreased after the occurrence of a negative bay. Consistent with this evidence, Anderson and Ness (1966) correlated an increase in the electron island fluxes with a decrease in the tail magnetic field.

Ness and Williams (1966) and Williams and Ness (1966) observed that the collapse of the high latitude trapping boundary during magnetic storms was correlated with an increase in the magnetospheric tail field. Cahill (1966) showed the inner magnetosphere to be inflated during a magnetic storm, and large periodic magnetic fluctuations were associated with a substorm. Lin and Anderson (1966) also observed that hydromagnetic waves attained their deepest penetration of the magnetosphere during times of high K_p. The dynamics of the inner magnetosphere have been further described by Carpenter (1966) who showed that the plasmapause moved inward when magnetic activity increased. Recently, Carpenter (1967) observed that the inward motion of the whistler ducts started about 12 minutes before the onset of a negative bay, and interpreted this motion in terms of an azimuthal electric field.

It is also becoming evident that substorms are essential in understanding the over-all dynamical processes of the magnetosphere. Fairfield and Cahill (1966) related the north-south component of the interplanetary and transition region magnetic field to the occurrence of auroral zone disturbances. When a sudden switch to a southward directed component of the magnetic field occurred, an increase in auroral zone disturbances followed. These results have been substantiated by Schatten and Wilcox (1967) who showed that K_p was generally higher when the interplanetary magnetic field had a southward directed component. It is interesting to note that the polar station used by Fairfield and Cahill in their analysis showed an almost immediate increase in the disturbance level after the switch to the southward directed magnetic field component, and that the associated substorm at auroral zone latitude occurred one to two hours afterward. This evidence lends support to the field line reconnection model for the convective magnetosphere proposed by Dungey (1963), Levy, et al (1964), and Axford, et al (1965). Recent observations by Heppner, et al (1967), however, indicate that the physical processes involved in a substorm may be more complicated.

The various forms of energetic electron precipitation and geomagnetic micropulsations were shown in papers I and II to depend very strongly on the local time at which they were observed. The results to be presented below give strong evidence for the fact that these two phenomena occur primarily during auroral substorms. It is clear, then, that the auroral substorm is part of a world-wide disturbance, and that it is the dynamical processes occurring throughout the magnetosphere which determine the local time characteristics of the substorm.

In order to generalize the concept of the auroral substorm to include all of the magnetospheric effects, we propose that the term magnetospheric substorm be used.

METHOD OF ANALYSIS

In order to study the relation of electron precipitation and magnetic micropulsation activity to the magnetospheric substorm, we have examined every electron precipitation and micropulsation event which occurred during 5 days of continuous data coverage at Flin Flon, Manitoba, Canada in August, 1965. Energetic electron precipitation data from balloons flown by the Berkeley and Sparmo groups and riometers, micropulsation data from induction coils and earth currents, and magnetometer data from magnetograms have been plotted to the same time scale, and combined into correlation plots for a single station. Sequences of such plots from three widely separated stations were then examined to determine the simultaneous, local time characteristics of the electron precipitation and micropulsations, and their relation to magnetospheric substorms. The three stations and their geomagnetic coordinates are: Flin Flon, Manitoba (63.6°N, 314.8°), College, Alaska (64.6°N, 656.5°), Kiruna, Sweden (65.3°N, 115.6°).

Chart records from Flin Flon containing micropulsation and x-ray data from September 1-9, 1966, and magnetograms from a number of auroral zone stations were also examined to determine the occurrence of substorms and the local time characteristics of the two phenomena during substorms. The period for which balloon x-ray data was available is shown in Figure 1, and the results of this analysis are presented in tabular form.

RESULTS

Figures 2 and 3 contain energetic electron precipitation, micropulsation and magnetometer data from August 19-20, 1965, which was the most active part of the five-day period. In the upper portion of each figure, large increases in riometer absorption or x-ray fluxes indicate the occurrence of electron precipitation events. In the center the amplitude and frequency of micropulsations at Flin Flon are plotted. The micropulsation data from College and Kiruna consisted of slow speed earth current recordings. Therefore, it was not possible to make quantitative scalings for these records. However, the occurrence and general character of micropulsation events at these stations can be recognized in the original data and are noted in Table 1. In the bottom of each figure, magnetograms from the three stations are superimposed to show the occurrence of substorms.

In Table 1 we have listed all the significant events which occurred at the three stations in the two-day period, August 19-20, 1965. It is shown in this table that each of these events occurred at a time when a magnetospheric substorm was in progress in the midnight sector. To further illustrate this relationship, we will examine two events in detail.

A. 1500 UT, August 19, 1965

The significance of the following observations is better understood when the geographic positions of the three stations are considered. Figure 4 shows their locations at 1500 UT; College was near 0500, Flin Flon at 0800, and Kiruna at 1600 local time.

Figure 2 shows a strong negative bay at College at 1400 UT indicating that an auroral breakup occurred over central Russia. No significant disturbance was evident on the Flin Flon or Kiruna magnetogram. The electron precipitation associated with this substorm occurred first at College, then at Flin Flon, and later at Kiruna. The electron precipitation at Flin Flon was modulated with a 10 second period and had occasional microburst groups. An examination of the riometer records from College and Kiruna shows that the electron precipitation was of worldwide extent. Somewhat earlier at 1400 UT a large amplitude, high frequency micropulsation event began at Flin Flon and was of the band limited irregular type described in paper II. The College earth currents show a high frequency micropulsation event which coincided in time with the one at Flin Flon. No micropulsation activity was evident in the Kiruna earth currents.

B. 0500-1500 UT, August 20, 1965

The geographic location of the three stations in terms of local time for this event is shown in Figure 5. The arrow indicates the region of local time through which each station rotates during the event.

An examination of the Flin Flon data (Figure 3) shows a close relation between all three records. A large negative bay began at 0500 UT and continued throughout the event. The magnetograms show the occurrence of at least three negative bays having maximum development at 0800, 1020 and 1240 UT. The electron precipitation began sharply at 0515 UT and had no evident structure. Micropulsations were slightly enhanced at this time in both amplitude and frequency. At 0640 UT an impulsive electron precipitation event was accompanied by a weak noise burst. A second impulsive electron precipitation event occurred at 0735 UT in conjunction with a very strong noise burst which underwent a rapid transition to band limited irregular pulsations. At 0820 UT the micropulsations reached a peak in frequency corresponding to a 10 second period, and modulated electron precipitation began with essentially the same period. From 0900-1100 UT, during the second substorm, only occasional fluxes of electrons were observed at Flin Flon, and a second band limited irregular event occurred. At 1115 UT a noise burst preceded the development of a third substorm. The electron precipitation started at 1230 UT and was modulated with long sequences of very regular 10 second pulsations. Band limited irregular micropulsations of similar period were still present.

Simultaneous balloon x-ray data for this event from Kiruna has been published by the Sparmo group (Ehmert, 1966). The x-ray data for 19-20 August, when available, has been plotted in place of the Kiruna riometer. At 0400 UT a slight increase in x-ray flux was observed at Kiruna, and reached a peak at 0500 UT. It should be noted that the onset time and the time of maximum x-ray intensity at Flin Flon and Kiruna were the same. From 0800-1000 UT a large flux of x-rays were detected at Kiruna. This period corresponded to the recovery phase of the first substorm, and coincided with the detection of large x-ray fluxes at Flin Flon. No indication of electron precipitation was recorded in the College riometer until the beginning of the second substorm during which low level electron fluxes were observed simultaneously at all three stations.

The most striking confirmation of the worldwide extent of the electron precipitation is demonstrated by the third substorm. Large electron fluxes were observed simultaneously over 12 hours of local time beginning at about 1200 UT. Electron precipitation begins first at College, and then almost simultaneously at Flin Flon and Kiruna.

Band limited irregular micropulsations were recorded at Flin Flon throughout the entire period 0800-1400 UT (2-8 local time). They were also observed at College during the third substorm, when College finally rotated into the local time interval 0200-1000. This type of micropulsation was not recorded at Kiruna since Kiruna had passed beyond the appropriate local time interval by the time the first substorm reached maximum development. Other major events occurring in the two-day period 19-20 August 1966 are described in Table I, and are shown to be related to the occurrence of a magnetospheric substorm.

OBSERVATIONS FROM SEPTEMBER 1-9, 1966

Simultaneous balloon x-ray and micropulsation data obtained at Flin Flon from September 1-9, 1966 were compared with standard magnetograms from several stations to further examine the relationship of electron precipitation and micropulsations to the magnetospheric substorm. The results of this analysis, presented in Table II, show that every micropulsation and electron precipitation event during this time occurred when a magnetospheric substorm was in progress somewhere on the night side. The temporal characteristics of the electron precipitation and micropulsations and the local time that they were observed at Flin Flon are noted, and are seen to agree with the local time occurrence patterns presented in papers I and II.

CONCLUSION

Having shown in papers I and II that, when electron precipitation and micropulsations occur at a given local time, they possess distinct temporal characteristics for each local time, evidence was presented in this paper that these two phenomena occur almost simultaneously throughout the auroral zone during an auroral substorm. Akasofu (1964) showed that at different phases of the substorm and at different longitudes, the physical appearance and temporal characteristics of the auroral forms possessed well defined structures and occurrence patterns. Even though simultaneous balloon x-ray and micropulsation experiments from many different stations have not been performed from the established local time occurrence pattern and the relationship to the substorm that was demonstrated above, it can be concluded that each specific form of energetic electron precipitation and micropulsation is probably occurring at its respective local time during some phase of the substorm development.

The fact that the occurrence of an auroral substorm is present not only in auroral disturbances, but also in electron precipitation and micropulsation activity throughout the auroral zone, indicates that it is the dynamical processes occurring in the magnetosphere which determine the local time characteristics of the substorm. Recent satellite observations have shown that many magnetospheric phenomena are correlated with substorms. In order to generalize the concept of the auroral substorm to include the world-wide disturbance characteristics and to emphasize the importance of the magnetosphere in auroral zone observations, we have suggested the term <u>magnetospheric substorm.</u>

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Table 1. Magnetospheric Substorms and Associated Electron Precipitation and Micropulsation Events -- 19-20 August 1965

Magnetospheric Substorms		Kiruna			Flin Flon				College		
UT	Comment	Local Time (UT+1)	Electron Precipitation	High Frequency Micro-pulsations	Local Time (UT-6)	Electron Precipitation	Type of Micro-pulsation	Corre-lation	Local Time (UT-10)	Electron Precipitation	Micro-pulsation
		19 August 1965									
0-3	Negative bay at Kiruna	0100-0400	Yes	Yes	1800-2100	None at Churc-hill (no Flin Flon x-ray data)	No	?	1400-1700	No	No
0400-0600	Negative bay at Flin Flon & Kiruna	0500-0900	Yes	Yes	2200-0200	Yes at Churc-hill(no Flin Flon x-ray data)	Noise bursts	?	1800-2200	No	No
0800-1100	Negative bay at College	0900-1200	Yes	No	0200-0500	No at Churc-hill (no Flin Flon x-ray data)	Band limited irregular	?	2200 0100	Yes	Yes
1300-1600	Negative bay at College	1400-1700	Yes	No	0700-1000	10 sec modu-lation micro-bursts	Band limited irregular	Yes	0300-0600	Yes	Yes
1700-?	Positive bay at Kiruna	1800-?	No	No	1100-?	Micro-bursts	Irregular magnetic impulse	Yes	0700-?	Yes	Yes
?-2400	Negative bay at Kiruna	?-0100	Yes	Yes	?-1800	No structure	No	No	?-1800	Yes	No

Table 1. (cont.)

Magnetospheric Substorms		Kiruna			Flin Flon				College		
UT	Comment	Local Time (UT+1)	Electron Precipitation	High Frequency Micro-pulsations	Local Time (UT-6	Electron Precipitation	Type of Micro-pulsation	Corre-lation	Local Time (UT-10)	Electron Precipitation	Micro-pulsation
			20 August 1965								
0500-0900	Negative bay at Flin Flon	0600-1000	Yes	No	2300-0300	Impulsive electron precipitation modulation	Noise bursts Band limited irregular	Yes	1900-2300	No	No
0900-1100	Negative bay at Flin Flon	1000-1200	Yes	No	0300-0500	10 sec modulation	Band limited irregular	Yes	2300-0100	Yes	No
1100-1400	Negative bay at College	1200-1500	Yes	No	0500-0800	Very regu-lar 10 sec modulation	Band limited irregular	Yes	0100-0400	Yes	Yes
2100-2400	Negative bay at Kiruna	2200-0100	Yes	Yes	1500-1800	No structure	Pearl pulsations	No	1100-1400	Yes	No

Note: At Kiruna and College only the occurrence of band limited irregular pulsations has been indicated.

Table 2. Types of Electron Precipitation and Magnetic Micropulsations Associated with Magnetospheric Substorms -- 1-9 September 1966

Magnetospheric Substorms					
Date	Time(UT)	Comment	Local Time Flin Flon (90^{o} WMT)	Type of Electron Precipitation	Type of Micropulsation
1 Sept	0730-1130	Multiple negative bays at College	0130-0530	Impulsive electron precipitation, 10 second modulation	Noise bursts and band limited irregular
1 Sept	1325-1520	Negative bay at College	0725-0920	10 second modulation, microbursts	None
1 Sept	1750-2200	Negative bay at College	1150-1600	Microbursts	Magnetic impulses
2 Sept	0000-0300	Negative bay at Leirvogur	1800-2100	None	None
3 Sept	0720-0930	Negative bay at Great Whale	0120-0330	PCA events, swells	Noise bursts
3 Sept	0930-1200	Negative bay at Great Whale	0330-0600	10 second modulation	Band limited irregular
3 Sept	1240-2200	Multiple negative bays at College	0640-1600	Modulation, swells, microbursts	Band limited irregular
4 Sept	0650-0800	Negative bay at College	0050-0200	No structure	Band limited irregular
4 Sept	1100-1400	Negative bay at Great Whale	0500-0800	Impulsive electron precipitation, 10 second modulation	Band limited irregular
4 Sept	1700-2300	Negative bay at Kiruna	1100-1700	Microbursts	Magnetic impulses

Table 2. (cont.)

Magnetospheric Substorms					
Date	Time(UT)	Comment	Local Time Flin Flon (90° WMT)	Type of Electron Precipitation	Type of Micropulsation
6 Sept	0230-0700	Negative bay at Leirvogur	2030-0100	Swells, 10 second modulation	Pre-midnight pulsation, noise bursts
6 Sept	0900-1430	Multiple negative bays at College	0300-0830	10 second modulation	Band limited irregular
6 Sept	1430-1700	Negative bay at Churchill	2100-2300	25 second modulation, microbursts	Quasi-sinusoidal pulsations, magnetic impulses
8 Sept	0300-0500	Negative bay at Churchill	2100-2300	No structure	Pearls, noise bursts, pre-midnight pulsation
8 Sept	0600-1000	Negative bay at Churchill	0000-0400	No data	Noise bursts
8 Sept	1000-1300	Multiple bays at Churchill, Great Whale, College	0400-0700	10 second modulation	Band limited irregular
8 Sept	1300-1700	Negative bay at College	0700-1100	10 second modulation	Band limited irregular with magnetic impulses
8 Sept	1800-2400	Negative bay at Kiruna	1200-1800	25-40 second modulation	Quasi-sinusoidal pulsation, sweeper
9 Sept	0430-0800	Disturbed?	2230-0200	Impulses, 10 second modulation, 5-25 msec bursts	Noise bursts
9 Sept	0810-1220	Multiple negative bays at College	0210-0620	10 second modulation	Band limited irregular
9 Sept	1340-1500	Negative bay at College	0740-0900	Modulation, microbursts	Irregular
9 Sept	1510-1800	Negative bay at College	0910-1200	Microbursts	None
9 Sept	2100-2200	Negative bay at Leirvogur	1500-1600	None	None
9 Sept	2330-0420	Negative bay at Leirvogur	1730-2220	Swells	None

FIGURE CAPTIONS

Figure 1 - High altitude balloon flights made from Flin Flon, Manitoba, Canada during early September, 1966.

Figure 2 - Electron precipitation, micropulsation and magnetometer data at three auroral zone stations, 19 August 1965.

Figure 3 - Electron precipitation, micropulsation and magnetometer data at three auroral zone stations, 20 August 1965.

Figure 4 - Position in local time of various auroral zone stations at 1500 universal time.

Figure 5 - Position in local time of various auroral zone stations at 0500 universal time.

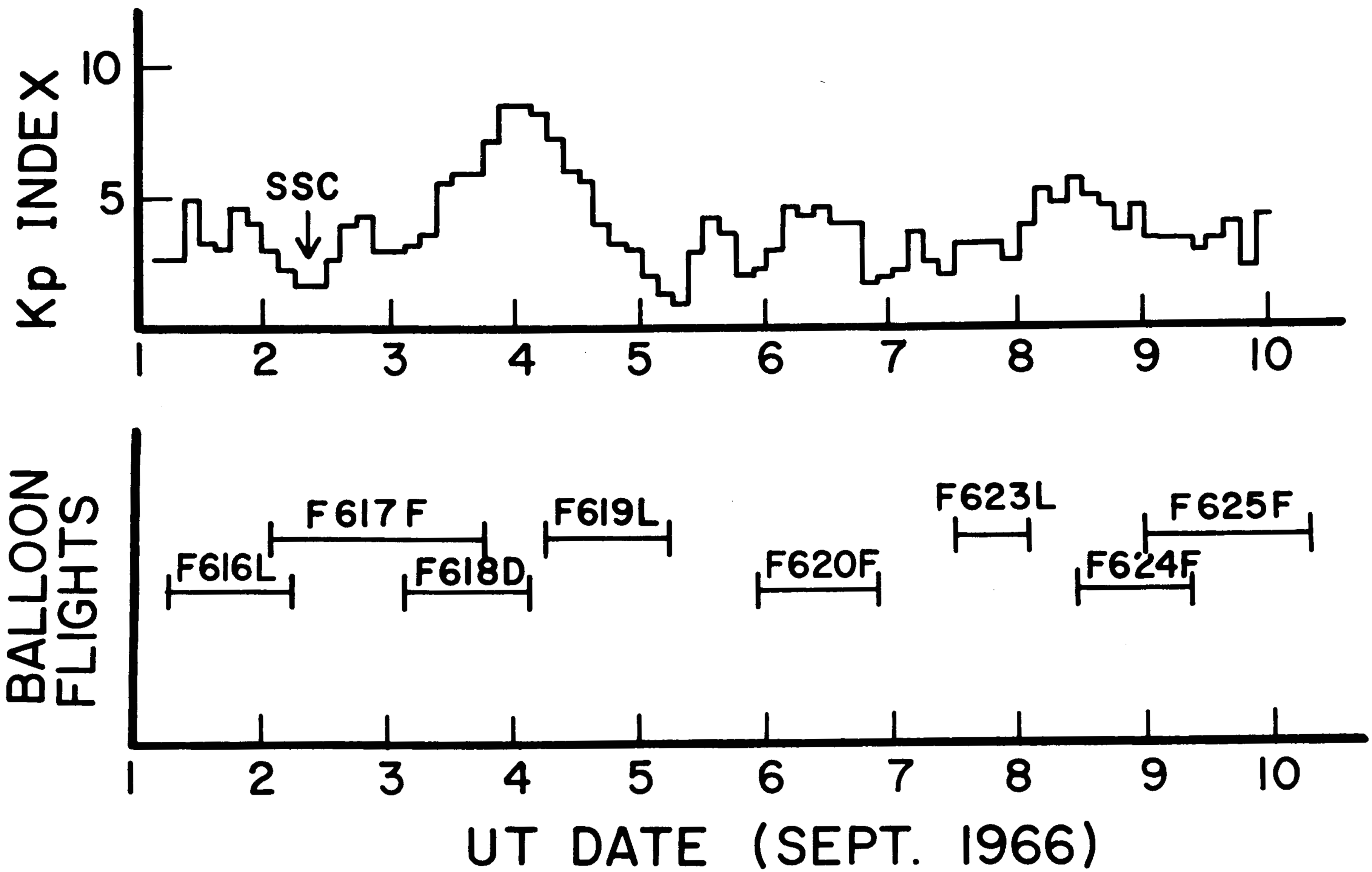
KEY WORDS

Magnetospheric substorm

Auroral substorm

Electron precipitation

Micropulsations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10
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SSC
BALLOON FLIGHTS
F616L
F617F
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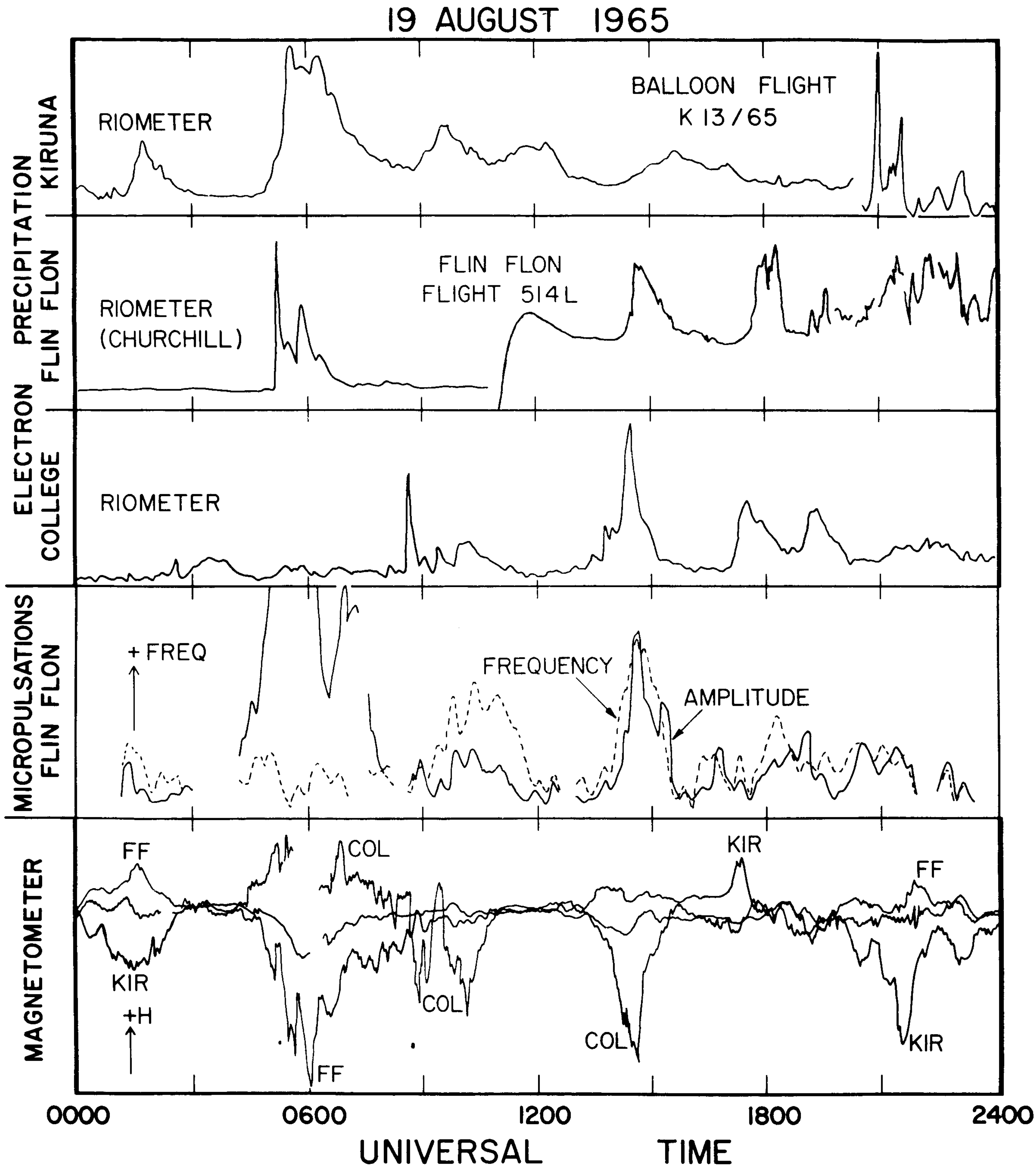
Figure 1


19 AUGUST 1965
RIOMETER
BALLOON FLIGHT
K 13/65
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(CHURCHILL)
FLIN FLON
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Figure 2

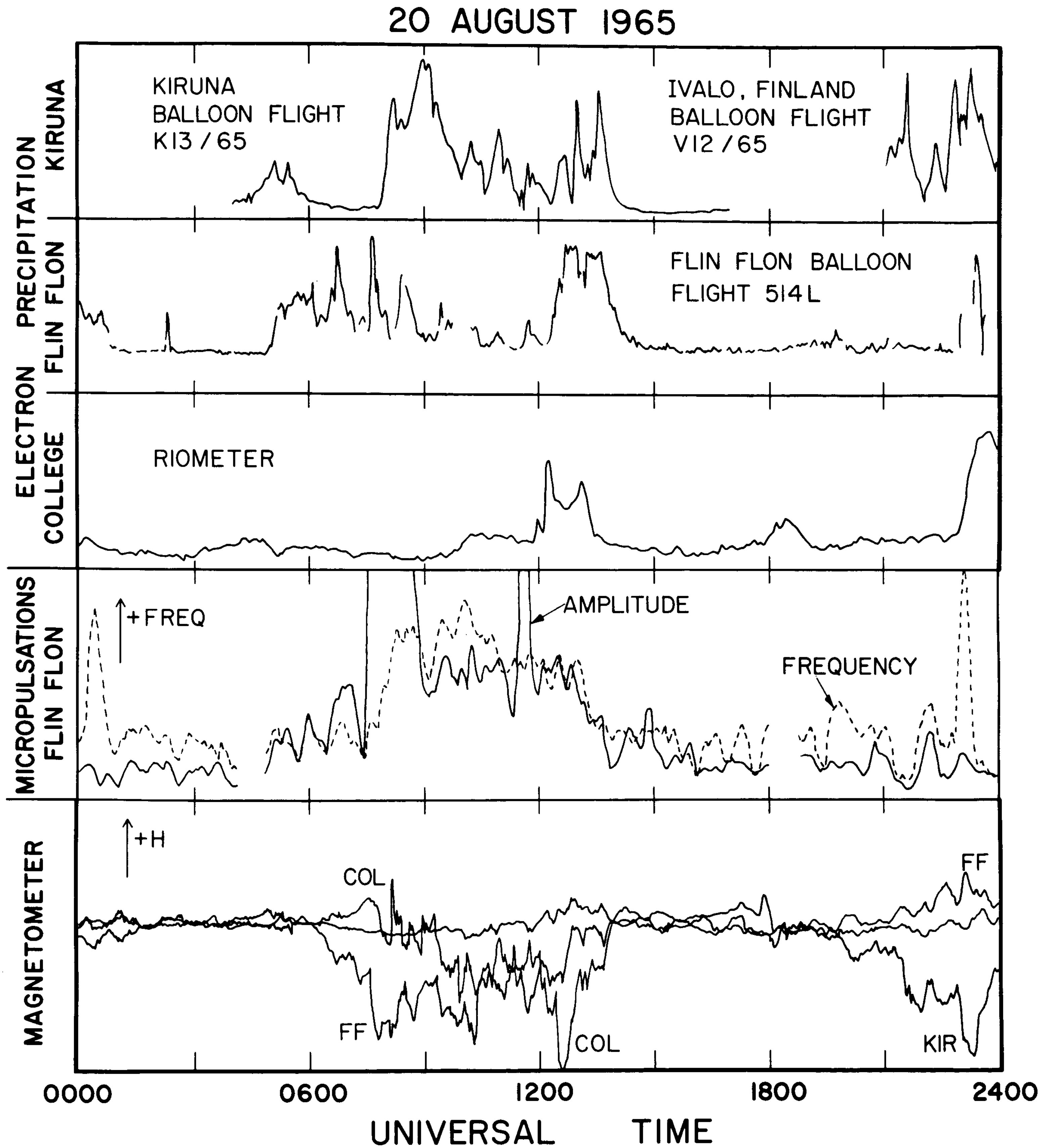
20 AUGUST 1965
PRECIPITATION KIRUNA
KIRUNA BALLOON FLIGHT K13/65
IVALO, FINLAND BALLOON FLIGHT V12/65
ELECTRON FLIN FLON
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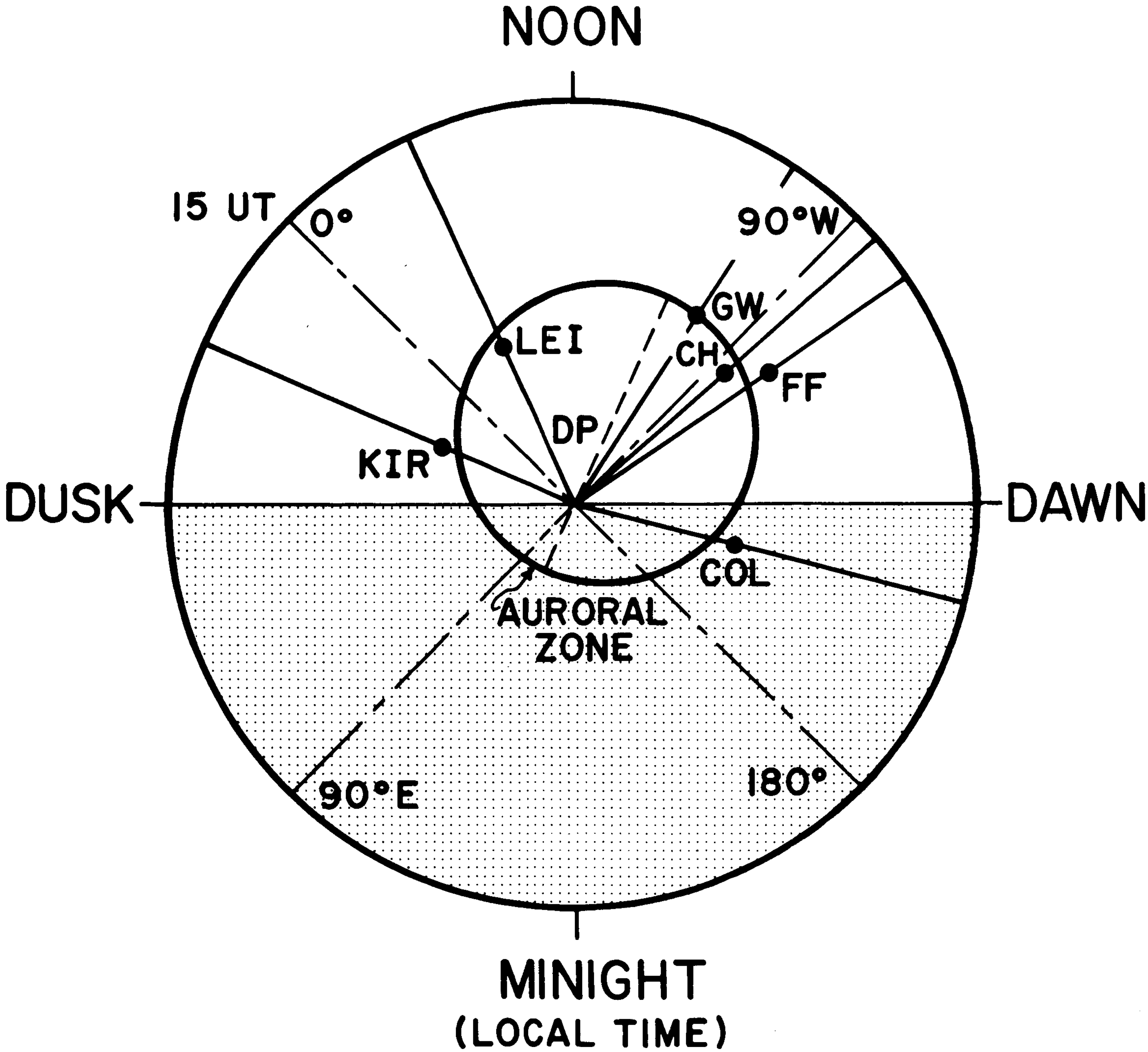
Figure 3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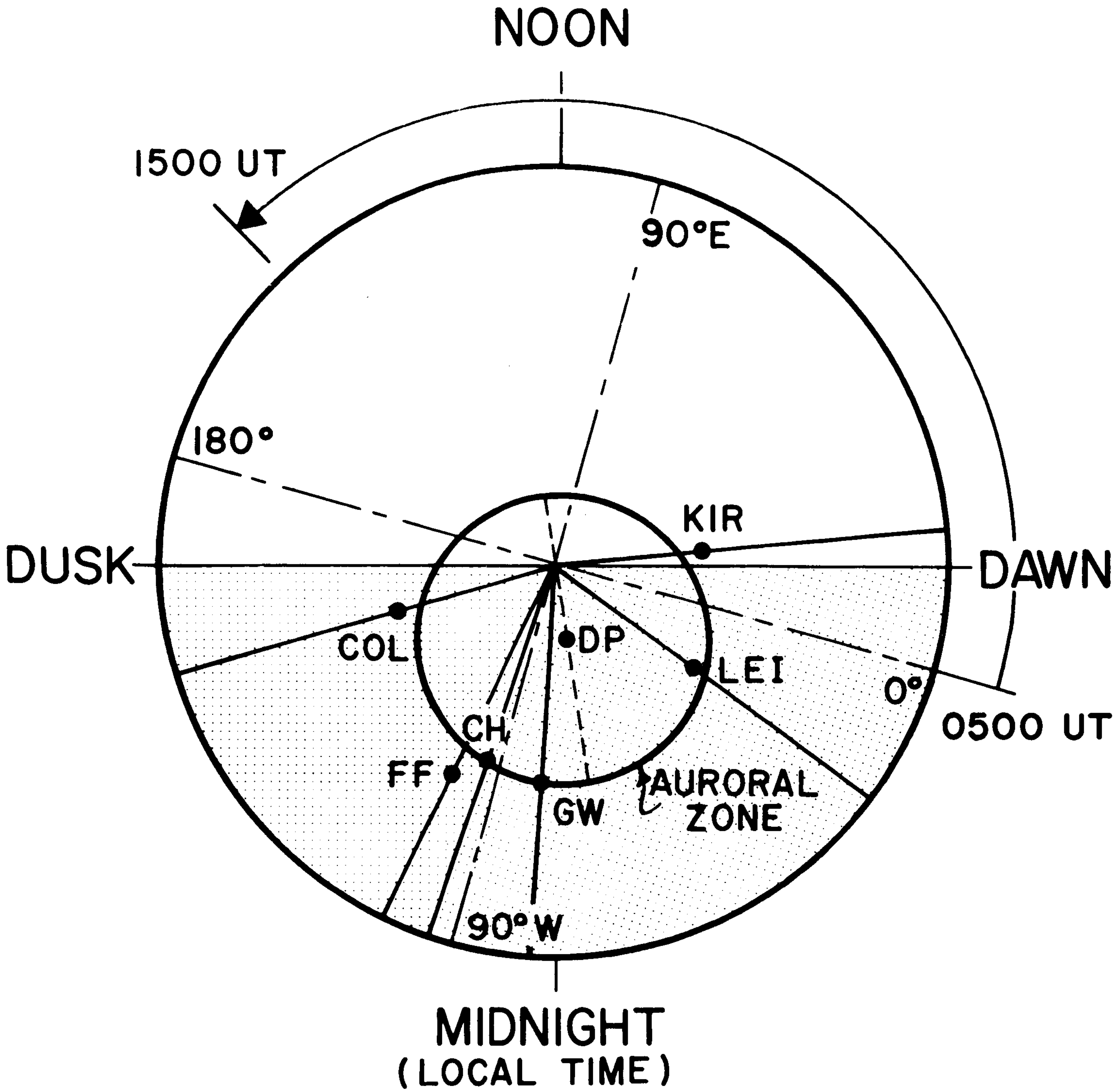
(LOCAL TIME)

Figure 4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ZONE
90° W
MIDNIGHT
(LOCAL TIME)

Figure 5